ON THE UNIT OF RADIATION [1]

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The memorandum which has been communicated to the society by Doctor Simpson at Doctor Ångström's request was also communicated to me as president of the meteorological section of the International Union for Geodesy and Geophysics by Doctor Wallén, Director of the Meteorological and Hydrographical Institute of Sweden. It was intended for the meeting of the section which was held at Prague, September 3 to 10 of this year. Doctor Wallén asked that it should be printed in the minutes of the meeting although it had failed to reach him at Prague, and only reached me after my return to London.

I have asked the secretary to include it as an appendix to the report of the meeting. The subject of units only came before the section in the form of a resolution asking the bureau to make a report to a future meeting upon the unitary systems and practices of the sciences, geodesy, seismology, terrestrial magnetism and electricity, meteorology, oceanography, vulcanology and hydrology, the seven sciences which are included within the scope of the union. The conjunction of the seven in one union makes an inquiry of that kind possible and useful.

Doctor Ångström's memorandum does not refer to so wide a field; it concerns itself merely with kilowatts per square decameter which I have employed for radiation in many publications, including a summary of radiations all over the globe in the procès-verbaux of the meeting of Madrid in 1924. I have therefore supplemented his memorandum by a note which is intended to explain that no one could be more cordially in sympathy with Doctor Ångström's aspiration for uniformity of units for solar radiation (and every other physical quantity employed in meteorology) than myself. The difference between us is simply a question of how uniformity can most speedily be secured.

Policy will, I believe, be on my side, and history will bear me out in claiming that *a common system of units for the science* should be the first consideration of all those who are desirous of securing uniformity in units. Community of system is more important than uniformity in any single arbitrary unit. My preference for kilowatts per square decameter for radiation as compared with gram calories per square centimeter per minute or per day, is chiefly that the first belongs to a system based upon energy and its conservation, while the second is purely arbitrary. That there are other advantages I can easily show, but its place in a system is its chief recommendation. There must be many meteorologists who agree with me on that point.

Doctor Ångström would apparently regard the units adopted by the pioneers in any subject of measurement as binding upon the science for all time. With all respect for the pioneers I can not agree with that view, and I do not think other meteorologists can. It is too double-edged. Would anyone, for example, expect to be listened to now if he claimed that the units employed by G. S. Ohm in the enunciation of his law, or by Faraday in his experimental researches on electricity, were binding on physicists and chemists for all time? Does not the science of physics, and do not electricians all over the world, whether they are specially concerned for science or not, owe an immense debt of gratitude to Gauss, Maxwell, Kelvin, Fleming-Jenkin, and others who formulated a system of units which enabled students to interpret Ohm's measurements and Faraday's researches in systematic units? Where would electricity be now if systematic units had been vetoed in the middle of the last century in favor of the Daniell's cell or the Siemens unit of resistance?

And thereby may I hang a tale about the power of system in obtaining uniformity. The founders of systems of units had to conciliate opposition by framing two alternative *systems*, the foot-grain-second and the centimeter-gram-second. My earliest practice with measurements of terrestrial magnetism was in foot-grain-second units. British magneticians were prepared to accept a system but not one based on meters and grams. The foot-grain-second system is now only a memory and for magnetism and centimeter-gram-second system is universal.

My own prepossession in favor of systematic units for meteorology dates from 1910, when I became responsible for publishing other geophysical data with the meteorological output of my office, data for terrestrial magnetism in properly ordered centimentr-gram-second units and those for meteorology which up to that time had appeared in the happy-go-lucky units of the pioneers like the gram calorie per square centimeter per minute. I am apparently more subject to scientific nausea in circumstances of that kind than some of my colleagues; but it should be remembered that I spent 20 years of my life in instilling the principles of experimental physics into the studious youth at Cambridge, and this endeavor to be logical and reasonable about physical questions for 20 years has perhaps left its mark on my constitution.

I admit that the endeavor to convince meteorologists that a system of units is one of the primary requirements for progress in the science is not only arduous in itself, but is also faced with many discouragements. In the isolation of the presidential chair of an international meeting when one catches the suggestion of opinion from this side and from that upon subjects in which one is personally profoundly interested, systematic measurement is apt to carry the appearance of a hopeless quest. So many considerations which seem to be remote enter into the crystallization of opinion. And yet somehow, when the votes have been taken, systematic meteorology has secured surprising and almost unexpected successes. Quite recently at Leipzig systematic units repeated the triumph which they secured in London two years ago and that will continue. "I am personally in favor of it, but as representative I can not vote for it," was one form of opinion in 1925; there is less feeling of being thought too much in advance of the age now.

Much, of course, is owing to the work on Dynamic Meteorology and Hydrography by V. Bjerknes and his collaborators. It lays the foundations of systematic meteorology and the appeal of the work on that basis is, to me at least, irresistible. Some day I should like to translate some of its formularies in terms of temperature and entropy and bring into greater prominence the idea of temperature as the "velocity of mean square," but that will not injure its systematic nature.

[1] Angström, A. On the unit of radiation used in meteorological treatises on actinometry. MO. WEA. REVIEW, August, 1927, 55: 364.

Doctor Ångström applauds Mr. Dines's critical attitude toward kilowatts per square decameter, but what about a gram calorie per square centimeter per day? I will leave them to settle what exactly radiation expressed in gram calories per day may mean, I always have to look it up when I want to know; and also whether a minute or a day is more nearly in accordance with systematic scientific practice. It is the gram calorie which unites the opposition to a systematic unit, but here I am on safe ground. The gram calorie is surely a survival of the middle nineteenth century and is not suitable for the twentieth. It echoes a claim to express the total amount of heat as a product of the amount of water warmed and the rise of temperature produced. I happened to live a good deal of my academic life among people who were using electrical methods to determine the dynamical equivalent of heat, and one of the lessons I carried away was that to regard the specific heat of water as constant was to be behind the times. Of course, the difference does not matter much, but it is just that kind of precision which distinguishes and ought to distinguish the twentieth century from the nineteenth.

And the suggestion that raising the temperature of water by radiation finds practical application in nature leaves me quite cold. If the sun shines on the sea or moist earth to imagine the process as effectively limited to the warming of water or earth is really too crude for modern purposes. The concentration of solar radiation necessary to cook a chop is much more likely to be expressed in kilowatts per square decameter than in gram calories per square centimeter per minute. And in practice the kilowatt per square decameter is exceptionally convenient as a glance at my table of radiation in the procès-verbaux of Madrid will convince any impartial reader. It gives the solar constant in three figures about 145 without a decimal point. What more can one want?

I have heard it rumored that Doctor Abbot disapproves of kilowatts per square decameter as a unit for solar radiation. I wonder if those of us who are in favor of systematic measurements could persuade him that in this particular he is mistaken. His purpose, with which we all sympathize, will best be served by getting his measurments incorporated into everyday use in all the many sciences which are concerned with solar radiation. That will be the easier the more widespread the practice of using a systematic unit to express energy of any kind. In solar physics as in climatology so long as we are dealing only with geographical or chronological comparisons an unrelated arbitrary unit is as good as another; but when it comes to crossing scientific frontiers a negotiable unit is the best passport.

I am myself convinced that in a science like meteorology, which makes use of almost every other science under the sun, the passport of systematic units is an absolute necessity for progress. I may not live to see it, but the time can not be far distant when that principle will be recognized even by ministers for air, and as soon as they are systematized our units will have become also uniform.

The race this year was a contest among 15 teams representing eight countries; the presence on some of those teams of veteran balloonists and experienced meteorologists gave the rivalry a decidedly keen character in a sportsmanlike way.

As usual, interest became keen concerning weather on the day before, when affairs meteorological were shaping themselves for the race. The weather map, however, seemed cold to the interest of the race, and disclosed a condition of barometric flatness which was as baffling as it was latent in possibilities. Two outlooks could be held as promising; one would be toward a drift northeastward or eastward beset more or less by thundershowers; the other a slow drift south and southeastward behind the area of depressed barometers which was central over the lake region.

On the 10th, the flat map had become a little more definite and at 8 a. m. a front of wind shift but mild temperature contrast could be delineated stretching southwestward from the LOW over Michigan. The situation recalls the 1922 Milwaukee balloon race when Westover, in a high-altitude drift, reached the wilds of Quebec, while the other ranking contestants took a low altitude drift and reached the region of Missouri. At Detroit, however, the sky never broke away its overcast long enough to permit even a fleeting glimpse of the upper clouds, and during most of the day an intermittent drizzle persisted, dulling the outlines of the lower clouds. So much depended on the position of the wind-shift line at the time of the take-off, that only by conceiving two definite plans of flight could the balloonists be sure of adopting successful tactics. If the line had reached Detroit when the starting hour arrived no alternative would be available than to ride out the slow but persistent winds of the front edge of the "polar" front; but if Detroit had still been in the warmer side of the LOW a drift eastward or eastnortheastward would have been worth adopting.

The take-off actually took place about two hours behind the passage of the wind shift, although no abrupt or marked change in the sky, wind, or temperature occurred with this passage, as indicated in part by Table 1. The chance for a brilliant coup at high altitudes was definitely lost to the certainty that rigid economy of ballast and gas, expert maneuvering against time, and a careful selection of altitude to obtain the fastest motion, would make up the elements of triumph.